A POSTPROCESSOR FOR THE MATSUURA 1000V CNC MACHINE AND A FANUC CONTROLLER (U)

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ABSTRACT

This paper describes the building of a postprocessor for a Matsuura 1000V three-axis computer numerical control milling machine and its Fanuc System 6B controller. The Matsuura machine parameters such as travel, axes of freedom, tool banks, and interpolation techniques are assessed and those that are required ara programmed into a machine data file generator sub-program. The appropriate command functions that are needed by simultaneous three-axis motion, the valid major and minor APT commands, and the site-specific machine control commands, are also included in the ostprocessor software. Punch file data editing software was written and was used to ready the data files for the shop floor.

RÉSUMÉ

Ce rapport décrit la construction d'un postprocesseur pour un machine-outil à contrôle numérique Matsuura 1000V et son contrôleur Fanuc Système 6B. Les paramètres de la Matsuura, tels que les déplacements, les degrés de liberté, les outils et les techniques d'interpolation sont évalués et ceux qui sont requis sont programmés dans un sous programme d'un générateur banque de données. Les fonctions de commande appropriées qui sont requises pour le mouvement simultané des trois axes, les commandes APT mineures et majeures valides, et les commandes spécifiques sont aussi inclus dans le logiciel. Un logiciel de modification de fichier fut écrit et utilisé pour préparer les fichiers de données pour l'atelier d'usinage.

EXECUTIVE SUMMARY

This paper describes the construction of a postprocessor for a computer-numerical control (CNC) milling machine/controller interface. This software enables the cutter location source files generated in the computer-aided design process to be translated into APT machine code. The major and minor words are defined and the relevant parameters determined from a knowledge of the Matsuura 1000V three-axis CNC machine and the Fanuc System 6B controller. Site-specific preparation software for the data files was written and is included in the description.

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1.0 INTRODUCTION

Computer-aided design and manufacturing (CAD/CAM) techniques are a rapidly growing part of engineering design. The CAD segment of CAD/CAM allows the engineer to construct a geometric model of the part in the computer memory and the CAM segment helps generate code that directs a computer-numerical control (CNC) machine to cut the part. One of the major requirements in any computer-aided design and manufacturing process is the capability of the design segment of the process to communicate effectively with the machining segment.

The computer-aided design process consists of the construction and manipulation of geometric models in the CAD database. Surfaces, splines and other curves define the shape and nature of the model itself. Surface parameters such as curve structure, gradients, continuity, and curve mesh density are used to generate the paths a machine cutter would have to take to cut the part from a blank.

In the machining segment, a computer-numerical control machine cuts the part. This machine is usually a three-axis milling machine that can perform cuts with simultaneous motion in the x-, y- or z- axes. It can be a four- or five-axis CNC machine or a CNC lathe. Whatever combination is employed, the machine is connected to a controller at its input that funnels the incoming data to the main machine memory. These input instructions are in APT (Automated Programming of Tools) language.

The data that are produced by the CAM process which contains generic machine instructions must be translated into an APT form that may be read by the CNC machine/controller combination. This translation is a software function and is performed by means of a postprocessor. This work reports the construction of a postprocessor for a Matsuura 1000V/Fanuc controller.

A study was made of the manuals of the Matsuura CNC machine and Fanuc controller. This enabled us to see the extent of available functions and commands. Many thousands of functions can be controlled by the command words to be defined and/or enabled to allow the machine to cut the part. An exact and detailed knowledge of the part geometry is required coupled with an understanding of the CNC machine and how the coupling between the two takes place.

Commands such as canned cycles, absolute and incremental coordinates, spindle speed, loads, feed rates and a host of others were extracted from the available APT command set and fed into the available command list in the postprocessor. Data formatting and transmission protocols all were defined. All active commands in the postprocessor were explicitly chosen and activated to give the best results for our Matsuura/Fanuc CNC machine/controller combination.

G-codes and M-codes have little universal applicability and must be defined in a way that suits the controller. Some are universal, others are globally defined and still others are locally defined. Many G-codes and M-codes can be defined covering most of the tool cycles that a three-axis CNC machine would use. Those defined in our program include those necessary to perform simultaneous three-axis movement for complex, three-dimensional surfaces. The same arguments apply to the linear and circulation interpolation functions, preparatory functions and tape functions, etc.

Machine controllers are known to be meticulous about data format and every care was taken to ensure that the correct number and size of fields were constructed coupled with the correct protocols required to transfer the data from a CNC minifile at the CAD/CAM site to a sister minifile on the shop floor.

The minifile device is a diskette device which may be set up to receive data that would be transmitted to a paper tape punch. The protocol set up for the input port makes the device appear as a paper tape punch to the ouptut port of the MicroVAX II computer. By this means, the ASCII data output by the postprocessor is loaded directly on to diskette. The diskette is loaded into a similar minifile device at the font-end of the Matsuura/Fanuc CNC device. A parallel post reader allows the controller to read the diskette by making the minifile appear like an infinite memory. Data are read off the diskette at any rate suited to the machine and controller.

2.0 BACKGROUND

The problems of generating complex sculptured surfaces are intimately linked to the evolution of numerical control (NC) technology itself. In the early 1960s, APT had progressed to the point that lines, circles and planes could be programmed and a start was being made on more complex surfaces like conics and quadrics. Work on these projects continued throughout the 1960s but little progress was made in the development of machining capabilities for free-flowing surfaces. As a result of this, a Sculptured Surfaces Project was initiated at the Illinois Institute of Technology Research Institute (sic) (IITRI) in 1968 (1). The Sculptured Surfaces Experimental (SSX) program was intended to develop the capability for three-dimensional surface machining for CNC technology. It was not until the end of the 1970s that the program brought forth major successes. Even in 1982, it was noted that much work remained to be done on sculptured surface machining problems (2).

Major software vendors for the CAD/CAM market such as IBM and McDonnell Douglas have invested heavily in the development of sophisticated three-dimensional CNC machining technology and today represent the state-of-the-art in the field. In sculptured surfaces technology, complex surfaces are built up as a network of patches which are defined mathematically as points, vectors and curves. The points form the basis of spline curves which, when combined in orthogonal sets, define the surfaces.

The surface definition is used as the basis for the computer-aided machining package. The cutting tools may be defined as flat end-mills, ballnose cutters, tapered-end tools and a host of others, but each has a specific geometric relationship with the part being machined. As the cutter moves over the surface of the part, the location of the center of the cutting tool moves on and off the surface depending on the gradient of the surface of the part at that point, that is, different segments of the cutting edge will be tangential to the part at different positions on the surface. From this, we can see that offset curves, which are different from the contour of the surface, have to be generated. Other factors are also present such as tool vibration, depth of cut, deformation and wear.

For any cutter location file (CL file or cutter location source file CLSF) the programming of cutter motion always concerns itself with a specific part of the tool: in the case of rotating cutters this is the center of the tool end. The offset curves are thus described by the locus of the center of the tool end. Actually, any sufficiently complex curve is made up of a large number of small line segments. CNC machines do have the capability to move in small line segments or in arcs (circular interpolation). Other curves have to be cut in increments of line segments. These segments may be made to approximate any other curve to an arbitrary degree of accuracy. The algorithm for generating the tool positions from parametric representations of curves and their line segments is shown in Appendix A.

A similar argument applies to the generation of offset surfaces for three dimensional tool paths. If we have a surface Σ over which a rotating cutter travels, then the surface Σ', traced out by the center of the tip of the cutter, will have properties analogous to those in the case above. The properties that are important are the continuity in position, slope and curvature. An illustration of this may be seen in Figure 1.

The geometric conditions that bind the surfaces Σ and Σ' together are their principal curvatures ϕ_{max} and ϕ_{min}. These are related by

$$\phi'_{max} = \phi_{max}/(1+ R\phi_{max}); \qquad \phi'_{min} = \phi_{min}/(1+ R\phi_{min})$$

where R is the end radius of the cutter moving over the surface Σ.

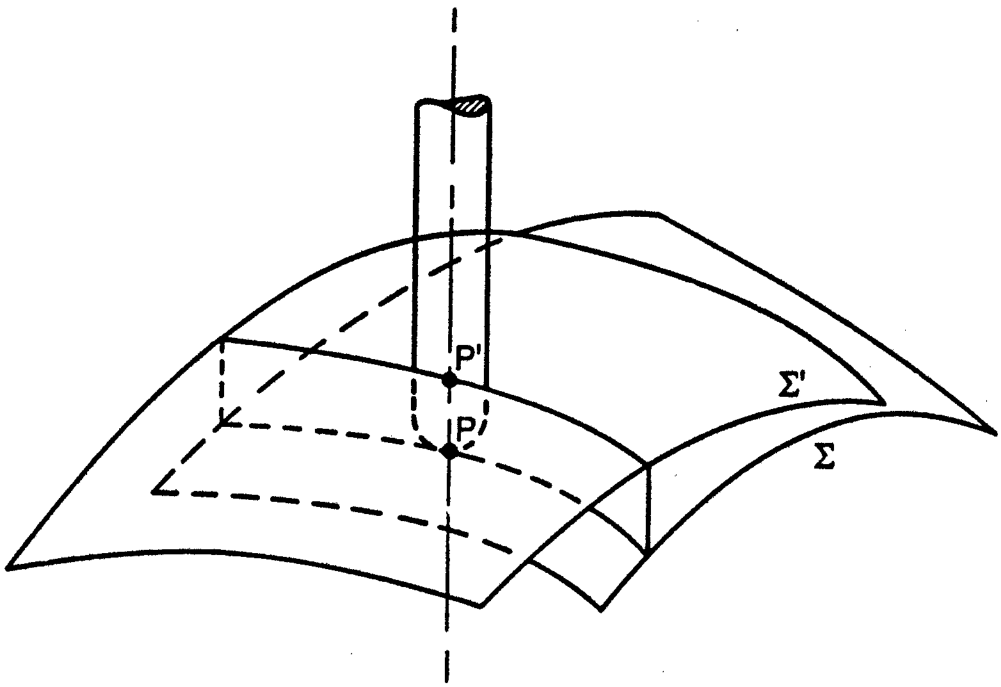

Figure 1: Betrand Surfaces for CNC Machining.

And so, in terms of the radii of curvature, $\mu = 1/\phi$, $\mu' = 1/\phi'$,

$$\mu'_{max} = \mu_{max} + R; \qquad \mu'_{min} = \mu_{min} + R$$

defining the surfaces as Bertrand surfaces, that is, surfaces with common normals.

3.0 DATA AND COMMAND STRUCTURES FOR THE MATSUURA/FANUC MACHINE/CONTROLLER COMBINATION

3.1 FORMATS

Whether programmed directly or generated by a CAD/CAM system, instructions for the CNC machine must be in a derivative of the APT language. A variety of "G-codes" and "M-codes" define the preparatory functions that the machine requires before start-up. Some of these are standard, some are specific to the machine and manufacturer and some are globally and locally defined within individual CNC programs.

Data is structured in the form of blocks. A block is any set of characters terminating in return or line feed (<CR>(return), <LF> (Line Feed) or <CR><LF>). Words are subsets of blocks consisting of an address and a numerical value e.g. X-1293. The address is a letter that indicates the meaning of the value following the address. X, Y, and Z represent coordinate axis motion; G represents motion modes such as linear or circular; S represents spindle speed and M ON/OFF controls for the machine tool.

A specific format must be followed for the word structure which is usually defined early in the program, e.g.

```
N04 G02 XL+044 YL+044...
```

where N04 is the sequence code defining the block and G02 sets up circular interpolation. In the following segment, XL+044..., the "X" represents the x-address, "Y" the y-address, "L" absolute or incremental movement, "+" no sign suppression, "0" leading zero suppression, and "44" four digits to the left and four digits to the right of the decimal point. This would describe the following command as an example:

```
G00X50125;
```

where "G00" indicates rapid traverse, "X" the address, "5" +0005 with sign and leading zero suppression and "0125" four digits to the right of the decimal point.

3.2 LOGICAL AND PHYSICAL DIFFERENTIALS

With regard to the maximum and minimum programmable dimensions, there are physical and logical varieties. Those given in the manual represent the maximum numerical limit, not the physical limit of the machine tool. Programmable maximum traverse might be 100 m along the x-, y- or z-axes but the actual distance possible may be 2 m. The same argument affects machine speed settings and other variables. The postprocessor must take these physical functions into account.

3.3 CONTROLLED AXES

The x-, y- and z-axes of a three-axis machine are the controlled axes. They may all be controlled simultaneously or, as with 2-1/2D machining, only the x- and y-axes. Four and five controllable axes are possible (for the Fanuc controller, not the Matsuura mill) and these are designated by A, B, C, U, V or W.

A maximum of four axes may be controlled simultaneously. There are six variables as one of the axes is a rotary axis involving an extra degree of freedom.

3.4 POSITIONING AND INTERPOLATION

G-codes are used to specify in which planes circular interpolation or cutter compensation will be used e.g. G17 for the xy-plane, G18 for the zx-plane and G19 for the yz-plane. Note that this command, G17Z50125, will move the z-axis.

The positioning function, G00, will have a different structure depending on whether absolute or incremental commands are used. If absolute, the co-ordinates must be commanded, if incremental, the distance from start point to end point. Usually, G90 will define absolute commands and G91 incremental. Positioning commands are important for starting paths over complex surfaces and are of the form: G00X...Y...Z...

G60 is used for positioning without backlash. This means that the positioning will be executed such that the tool approaches the co-ordinate from the same direction. This is important only at the limits of accuracy of the machine, that is, at dimensions of approximately 0.025mm (0.001 inch.)

Further positioning criteria may be specified including the addition of reference points. G-codes 27 through 30 govern this parameter. Reference points are points that are fixed on the machining plane to which and from which positioning commands are measured. What co-ordinate values are written after the G-codes depend on whether absolute or incremental movement has previously been specified (G90 or G91).

Various work co-ordinate systems may be set up for different machining tasks on the work but to relate all of these an absolute zero point is established by the G92 command. G92X...Y...Z... will establish a co-ordinate system that is based a specific distance from the tool position. After this, any absolute commands refer to the co-ordinate value in the work system.

4.0 COMPENSATION COMMANDS

4.1 TOOL LENGTH COMPENSATION

The tool length is that part of the tool that projects below the quill on the machine spindle. This may vary according to what size of cutter is being used and how it is mounted. As different tools will likely be used on the same part, a compensation function defined by a G-code (G43, G44, or G49) enables the terminal point of the movement commands in the z-axis to be shifted by an amount set in the offset memory. The value of this parameter is set after the G-code by means of an H-code e.g. G43 Z7.5547 H2.000. Clearly, this can set the difference between the actual tool length and the value used in the program. Compensation may thus be achieved without re-programming.

Offsets other than tool length compensation can be offsets in other axes and here codes G45 to G48 operate. However, these commands are not modal and refer only to the block in which they are defined.

5.0 SPINDLE AND TOOL FUNCTIONS

5.1 SPINDLE SPEED

S-codes apply to the spindle and its functions. Speed is specified by a four-digit number after the "S". Constant surface speed may also be specified. This function calculates the correspondence between tool position changes on the surface and the spindle rotation speed so that a feedback correction will be supplied to the spindle if the surface speed varies. This is required for some types of surface machining. G-codes G96 and G97 call the constant surface speed function ON or OFF. This function only applies to the rotary fourth axis.

5.2 TOOL FUNCTION

The command "T" is followed by a two-digit number specifying the tool to be used.

6.0 MISCELLANEOUS FUNCTIONS

6.1 M-CODES

M-codes require a two-digit argument and are used to specify particular machine functions. Only one M-code per block can be used and if more appear only the last one is effective. These codes are not universal and are a function of the machine tool builder.

M30 rewinds the tape at the end of the program, or, if a disk memory is used, it means that the operations are reset to the ER code (the "%" sign) at the beginning of the program and the NC unit is reset. With M00 all cycle operations are stopped after any block containing this command.

7.0 POSTPROCESSOR FUNCTIONS

7.1 FUNCTION DEFINITION

The following summary of defined functions is that which was used for a Matsuura 1000V three-axis milling machine and a Fanuc System 6M controller. Other functions may be defined and/or enabled for this particular combination but this set was satisfactory for most machining needs. The valid major and minor words at the end of the postprocessor information indicate those APT words and terminology that are enabled by the postprocessor. Words may be produced in the machining function (which produces the generic CL-file) that may not have been included in the set of definitions incorporated in to the postprocessor. This will lead to errors. All linear dimensions are quoted in imperial units unless otherwise specified.

WORD ADDRESS FORMATS

WORD ADDRESS	DIGITS	DECIMAL PLACES	SUPPRESS PLUS	SUPPRESS MINUS	SUPPRESS LDZERO
N	4	0	YES	YES	NO
G	2	0	YES	YES	NO
X	7	4	YES	NO	YES
Y	7	4	YES	NO	YES
Z	7	4	YES	NO	YES
I	7	4	YES	NO	YES
J	7	4	YES	NO	YES
K	7	4	YES	NO	YES
F	4	1	YES	NO	YES
S	4	0	YES	YES	YES
D	2	0	YES	YES	NO
T	4	0	YES	YES	NO
M	2	0	YES	YES	NO

WORD ADDRESS	SUPPRESS TRZERO	OUTPUT DECIMAL	TRAILING CHARACTER	FUNCTION
N	NO	NO	NOT USED	SEQUENCE NUMBER
G	NO	NO	NOT USED	PREPARATORY G CODES
X	YES	YES	NOT USED	X COORDINATE
Y	YES	YES	NOT USED	Y COORDINATE
Z	YES	YES	NOT USED	Z COORDINATE
I	YES	YES	NOT USED	CIRCLE CENTER X
J	YES	YES	NOT USED	CIRCLE CENTER Y
K	YES	YES	NOT USED	CIRCLE CENTER Z
F	YES	YES	NOT USED	IPM/MMPM
S	NO	NO	NOT USED	RPM
D	NO	NO	NOT USED	TOOL ADJUST NO.
T	NO	NO	NOT USED	TOOL NUMBER
M	NO	NO	NOT USED	MISCELLANEOUS CODE

PREPARATORY FUNCTION LIST

G-CODES	FUNCTION	POSTPROCESSOR COMMAND
00	POSITIONING MODE	RAPID
01	LINEAR INTERPOLATION MODE	GOTO
02	CLOCKWISE CIRCULAR INTERPOL-ATION	SET/MODE,LINCIR
03	COUNTERCLOCKWISE CIRCULAR INTERPOLATION	SET/MODE,LINCIR
17	XY PLANE	CIRCULAR INTERPOLATION
17		CUTCOM/XYPLANE
18	ZX PLANE	CIRCULAR INTERPOLATION
18		CUTCOM/ZXPLANE
19	YZ PLANE	CIRCULAR INTERPOLATION
19		CUTCOM/YZPLANE
20	IMPERIAL (INCH) FORMAT	
21	METRIC FORMAT	
90	ABSOLUTE MODE	SET/MODE,ABSOL
91	INCREMENTAL MODE	SET/MODE,INCR
96	SFM/SMM SPINDL MODE	SPINDL/SFM(SMM)
97	RPM SPINDL MODE	SPINDL/RPM

MISCELLANEOUS FUNCTION CODES

M CODE	FUNCTION	POSTPROCESSOR COMMAND
00	STOP OPERATION	STOP
01	OPTIONAL STOP	OPSTOP
02	END OF PROGRAM	END
03	DEFAULT SPINDLE DIRECTION	SPINDL/ON
03	SPINDLE CLOCKWISE	SPINDL/..,CLW
04	SPINDLE COUNTERCLOCKWISE	SPINDL/..,CCLW
05	SPINDLE STOP	SPINDL/OFF

06	AUTOMATIC TOOL CHANGE	LOAD/TOOL
00	MANUAL TOOL CHANGE	LOAD/TOOL,...,MANUAL
07	COOLNT MIST CODE	COOLNT/MIST
08	COOLNT FLOOD CODE	COOLNT/FLOOD
08	DEFAULT COOLANT ON	COOLNT/ON
09	COOLNT OFF	COOLNT/OFF
30	END OF PROGRAM, REWIND	REWIND

FEED RATE PARAMETERS

DEFAULT FEED RATE	10 IPM
MAXIMUM IPM/MMPM FEED RATE	400.0 IPM
MINIMUM IPM/MMPM FEED RATE	0.1 IPM
RAPID TRAVERSE RATE	400.0 IPM

MACHINE TRAVEL LIMITS

X AXIS MINIMUM	-1000.0000
X AXIS MAXIMUM	+1000.0000
Y AXIS MINIMUM	-1000.0000
Y AXIS MAXIMUM	+1000.0000
Z AXIS MINIMUM	-1000.0000
Z AXIS MAXIMUM	+1000.0000

RUN TIME PARAMETERS

NUMBER OF LINES PER PAGE OF LISTING	39
NUMBER OF COLUMNS PER LINE OF LISTING	132
COMMENTARY LISTING CONTAINS:	
RECORD NUMBER	
X COORDINATE	
Y COORDINATE	
Z COORDINATE	
CURRENT IPM/MMPM	
CURRENT RPM	
BLOCK TIME	
NUMBER OF G CODES PER BLOCK	4
LISTING OUTPUT	LINEPRINTER.FIL
LISTING DATA	UNPACKED
PUNCH TAPE OUTPUT TO UGFM TEXT FILE	PUNCH.PTP
PAPER TAPE OUTPUT TO SYSTEM LOGICAL	UGPTR
LINEPRINTER OUTPUT	UGII$PRINTER
PUNCH TAPE FORMAT	ISO,RS-358. EVEN PARITY
END OF BLOCK CODE	<CR><LF>
INPUT DIMENSIONS	INCH
OUTPUT DIMENSIONS	INCH
POSTPROCESSOR ERROR MESSAGES	TERMINAL
IF LISTING OUTPUT, ERRORS ON LINEPRINTER OUTPUT	
LEADER LENGTH	0

TRAILER LENGTH	0
LEADER CHARACTERS	NULLS
SEQUENCE NUMBER INCREMENT	10
NUMBER OF BLOCK PER SEQUENCE NUMBER	1

SPECIAL TAPE CONTROL GUIDES

CONTROL OUT ISO CODE	(
CONTROL IN ISO CODE	)
CONTROL OUT EIA CODE	<032>
CONTROL IN EIA CODE	<112>
INITIAL CODE AT START OF TAPE	REWIND,STOP,END-OF-BLOCK
END OF TAPE CODE	NOT REQUIRED

SPINDLE PARAMETERS

RPM LIMITS	
MAXIMUM RPM, RANGE 1	9999
MINIMUM RPM, RANGE 1	1
SPINDLE DIRECTION CONTROL	M CODES

SPINDLE DIRECTION M CODES OUTPUT FOR EVERY SPINDLE STARTUP
SPINDLE DIRECTION CODE & RPM CODE IN SAME BLOCK

SPINDLE STOP & DIRECTION CHANGE	NOT REQUIRED

TOOL CHANGE PARAMETERS

MAXIMUM TOOL NUMBER	99
MINIMUM TOOL NUMBER	1
TIME FOR TOOL CHANGE	0.20 MINUTES

TOOL CODE WILL NOT BE COMBINED WITH MOTION

MAXIMUM TOOL ADJUST NUMBER	99
MINIMUM TOOL ADJUST NUMBER	0

TOOL LENGTH COMPENSATION IS ACTIVATED BY OFFSET REGISTER ONLY
TOOL LENGTH COMPENSATION IS CANCELLED BY DO
TOOL LENGTH COMPENSATION CODES OUTPUT WITH Z-MOTION
TOOL CODE OUTPUT IN SAME BLOCK WITH TOOL CHANGE M06
TOOL CODE NOT OUTPUT IF PRE-SELECTED

CIRCULAR INTERPOLATION PARAMETERS

MAXIMUM RADIUS FOR CIRCULAR INTERPOLATION	999.9999
MINIMUM RADIUS FOR CIRCULAR INTERPOLATION	0.0001
PLANES OF CIRCULAR INTERPOLATION	XY, YZ & ZX

ARC CENTER DEFINITION — ABS & INCR MODES
I, J & K REPRESENT THE DISTANCE FROM ARC START TO CIRCLE CENTER
ALL PROGRAMMED ARCS DIVIDED UP INTO SEGMENTS OF 360 DEGREES OR LESS
HELICAL ARCS OUTPUT — LINEARLY
CIRCULAR INTERPOLATION CLW & CCLW G CODES ARE MODAL

LINEAR INTERPOLATION PARAMETERS

MIMIMUM MACHINE RESOLUTION (INCH)	0.0001
AXIS OF SIMULTANEOUS MOTION IS	3; X,Y,Z IN SAME BLOCK
ABSOLUTE MODE	G90
INCREMENTAL MODE	G91
VERTICAL DOWNWARDS	-Z AXIS
DEFAULT SPINDLE AXIS FOR WORK PLANE CHANGE AND CYCLE LOGIC	+Z AXIS

POSTPROCESSOR WILL OUTPUT RAPID TRAVERSE MOTIONS IN TWO BLOCKS IF A SPINDLE AXIS MOTION AND EITHER AN X- OR Y-AXIS MOTION OCCURS

COORDINATE CONVERSION PROGRAMMED PART COORDINATES TO MACHINE COORDINATES

COORDINATE DEFINITIONS

XP= PROGRAMMED(X)+ TRANS(X)- ORIGIN(X)
YP= PROGRAMMED(Y)+ TRANS(Y)- ORIGIN(Y)
ZP= PROGRAMMED(Z)+ TRANS(Z)- ORIGIN(Z)
CARTESIAN MILL COORDINATE SYSTEM

MACHINE- X= XP
MACHINE- Y= YP
MACHINE- Z= ZP+ ZOFF

POSTPROCESSOR COMMAND FORMATS

VALID MAJOR WORDS	VALID MINOR WORDS
AUXFUN	N
CHECK	XAXIS,N,N
	YAXIS,N,N
	ZAXIS,N,N
COOLNT	ON
	OFF
	FLOOD
	MIST
END	
FEDRAT	N
	IPM,N
	MMPM,N

	IPR,N	
	MMPR,N	
GOHOME	X,Y,Z	
	XAXIS,N	
	YAXIS,N	
	ZAXIS,N	
INSERT		
LEADER	N	
LOAD	TOOL,N	
	ZOFF,Z	
	MANUAL	
	ADJUST,N	
OPSKIP	ON	
	OFF	
OPSTOP		
ORIGIN	X,Y,Z	
PARTNO		
PPRINT		
PERFUN	N	
RAPID		
REWIND		
SELECT	ZAXIS,N	
SEQNO	N	
	INCR,N	
	OFF	
	CN	
	NEXT	
	AUTO	
SET	ADJUST	,N
		ON
		OFF
SET	MODE	ABSOL
		INCR
		LINEAR
		LINCIR
SPINDL	N	
	ON	
	OFF	
	RPM,N	
		CLW
		CCLW
		RADIUS
STOP		
TIME	N	
	SCALE,S	
	NOW	
TMARK	N	
	AUTO	
TRANS	X,Y,Z	

8.0 POSTPROCESSOR PROPERTIES

8.1 MDF TEMPLATE

The MDF template is a skeleton machine data file (MDF) generator resident in Unigraphics. Parameters for the machine/controller combination used may be fed into the template interactively. These values are compiled into a file, FILE.MDF, which is then the active file that will take the *.CLS file generated by the tool path function in Unigraphics and translate the GOTO statements of generic tool motion into x-, y- and z- axis coordinate motion in APT instruction code for the machine.

8.2 POSTPROCESSOR OUTPUT

Three files are output by the postprocessor for every CLSF input. They are FILE.LPT, FILE.CLF, FILE.PTP, and the *.PTP files are the paper tape-ready files. They may be punched directly on paper tape by means of the program "XLATOR" or downloaded to a floppy disk device. The output of XLATOR is a standard ASCII file.

Before the ASCII file is ready for downloading on to the floppy disk drive, more editing is required. The APT command structure is determined by the postprocessor when the *.PTP punch file is generated, but this may still not contain all the information required by the CNC shop floor operator. Various commands are necessary to set the machine in a start-up mode, determine the tools used, the motion limits, the origin positioning and other preparatory functions. These commands are written out in detail and stored in a file, HEADER.TXT in the GRIP (Graphics Interactive Programming Language) module. The similar command set used to shut down the machine after use is likewise contained in a file, FOOTER.TXT. These must be added to each machining file prior to downloading.

The software to perform this task is contained in the program, FILEADDR.GRS, which is shown in Appendix B. The program adds these commands, deletes unwanted lines, cleans up the format and stores the file as the punch file ready for downloading. The preliminary commands and the file closure commands may be seen in Appendix C.

9.0 CONCLUSION

Postprocessors are an important part of the CAM link to CAD. They take the data produced by the CAM machining module and generate a file of APT command instructions for the CNC machine and controller. Each postprocessor is specific for a particular CNC machine/controller combination of which there are many. The description of the postprocessor contained herein is completely satisfactory for the Matsuura 1000V/Fanuc 6B system and may be used with very little modification on other Matsuura CNC machines and their Fanuc System 6 controllers.

10.0 ACKNOWLEDGEMENTS

I would like to thank Peter Clark of the Communications Research Center Model Shop for many helpful discussions concerning the CNC machine and controller.

11.0 REFERENCES

1. Krouse J. K. "What Every Engineer should know about Computer-Aided Design and Computer-Aided Manufacturing", M. Dekker Inc., New York, 1982, p. 93.

2. Ibid, p. 94.

APPENDIX A

APPROXIMATIONS FOR SURFACE CURVATURE

A rational polynomial curve may approximated by a sequence of linear segments. These can approach the curve to an arbitrary degree of accuracy. Consider Figure A-1. From geometry we can see that

$$r^2 = (L/2)^2 + (r-\mu)^2$$

where L is the step length and r the radius of curvature. From this

$$L^2 = 4\mu(2r-\mu)$$

showing that r can be calculated from the formula for the true curve. For a full description of the approximation methods see "Surface Engineering Geometry for Computer-Aided Design and Manufacture", Davies B.J., Qiulin D., John Wiley & Sons, New York, 1987.

Parametric Surface Milling

The curves that make up sculptured surfaces can be used to direct the machine tool. The algorithm calculates approximations to the curves on the surface (see Figure A-2).

Consider a surface patch $\mathbf{r}(u,w)$. The output is a set of x-, y- and z-coordinates. The surface is machined along one or other of the parameter curves i.e. along u when w is set. If the increments in the parameter variation are $\delta u = 0.01$, $\delta w = 0.01$, then the surface equations are evaluated approximately 30,000 times.

To keep the number of operations to a mimimum, Horner's rule is used for factoring the cubics:

$$\mathbf{r}(u) = [(\mathbf{d}u + \mathbf{c})u + \mathbf{b}]u + \mathbf{a}$$

where **a**, **b** and **c** are vector coefficients. Again, keeping the problem of large numbers of calculations in focus, the method of forward differences is used. Consider the forward-difference of a vector function $\mathbf{r}(u)$:

$$\delta\mathbf{r}(u) = \mathbf{r}(u + \epsilon) - \mathbf{r}(u)$$

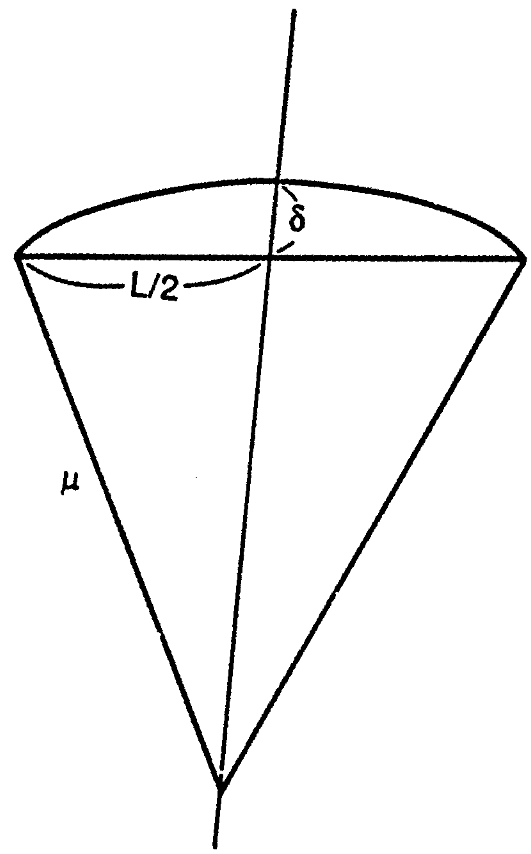

Figure A-1: Segmentation of Polynomial Curve.

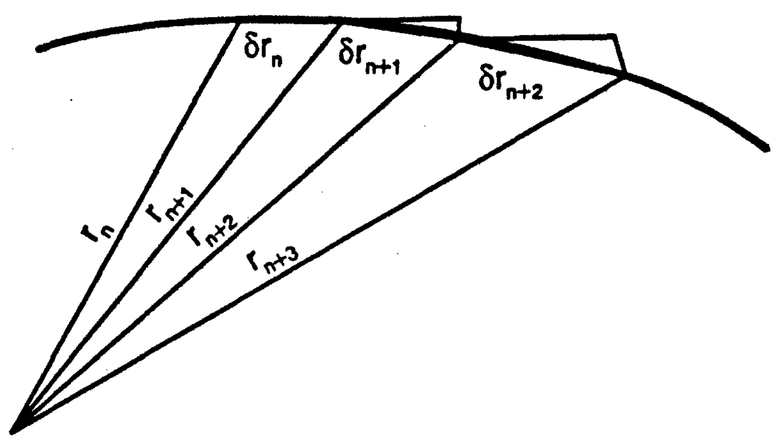

Figure A-2: Linear Approximation of Polynomial Curve.

where $\epsilon > 0$ and is the increment in u. Changing the equation around

$$\mathbf{r}(u+\epsilon) = \mathbf{r}(u) + \delta\mathbf{r}(u)$$

And suppose that after each iteration, after each addition of ϵ, the value changes from the n th to the (n+1) th:

$$\mathbf{r}_{n+1} = \mathbf{r}_n + \delta\mathbf{r}_n$$

and so $\mathbf{r}_n = \mathbf{r}(u_n)$. Applying this to a cubic:

$$\mathbf{r}(u) = a + bu + cu^2 + du^3$$

and the difference equation becomes:

$$\delta\mathbf{r}(u) = a + b(u+\epsilon) + c(u+\epsilon)^2 + d(u+\epsilon)^3 - (a + bu + cu^2 + du^3)$$

$$= (b\epsilon + c\epsilon^2 + d\epsilon^3) + (2c\epsilon + 3d\epsilon^2)u + 3d\epsilon u^2$$

which is a second-order polynomial. Now consider $\delta\mathbf{r}(u)$ to be a function and evaluate $\delta(\delta\mathbf{r}(u))$:

$$\delta^2\mathbf{r}(u) = 2c\epsilon^2 + 6d\epsilon^3 + 6d\epsilon^2 u$$

or in terms of the index, n,

$$\delta\mathbf{r}_{n+1} = \delta\mathbf{r}_n + \delta^2\mathbf{r}_n$$

If $\delta^2\mathbf{r}(u)$ is considered as the function, we deduce that

$$\delta^3\mathbf{r}(u) = 6d\epsilon^3$$

Observing that the third difference is a constant, and that

$$\delta^3\mathbf{r}_n = \delta^2\mathbf{r}_{n+1} - \delta^2\mathbf{r}_n$$

Re-arranging and substituting n-2 for n:

$$\delta^2\mathbf{r}_{n-1} = \delta^2\mathbf{r}_{n-2} + 6d\epsilon^3$$

and repeating the process $1/\epsilon$ times starting from n=0:

$$\delta^2\mathbf{r}_{n+1} = \delta^2\mathbf{r}_n + \delta^3\mathbf{r}_0$$

It should be noted that the size of the increment, ϵ, determines the surface tolerance, that is, how closely the line segments match the bi-cubic patch. This is not the same tolerance as the stock or stepping values used in the machining set-up instructions. This method of machining surfaces is readily adapted to meshing several patches together, provided that their surface edges match in gradients and continuity.

The final solution may be written in matrix form:

$$\begin{array}{r} r_0 \\ \delta r_0 \\ \delta^2 r_0 \\ \delta^3 r_0 \end{array} \quad \begin{array}{cccc} 1 & 0 & 0 & 0 \\ 0 & \epsilon & \epsilon^2 & \epsilon^3 \\ 0 & 0 & 2\epsilon^2 & 6\epsilon^3 \\ 0 & 0 & 0 & 6\epsilon^3 \end{array} \quad \begin{array}{c} a \\ b \\ c \\ d \end{array}$$

or

$$R_0 = E(\epsilon)A$$

where A is a 1 by 4 matrix of the curve coefficients. Reverting to our parametric form:

$$r(u,w) = [1\ u\ u^2\ u^3]A \begin{array}{c} 1 \\ w \\ w^2 \\ w^3 \end{array}$$

where A is a 4 by 4 matrix of the surface coefficients. Or again:

$$r(u,w) = UAW^T$$

APPENDIX B

FILE EDITING SOFTWARE

The following software was written in GRIP to edit the punch file and add header commands and footer commands as well as editing out null lines.

```
$$ PROGRAM:    FILEADDR.GRS
$$
$$ PROGRAM WILL ADD FILE HEADER AND FOOTER
$$ COMMANDS AND EDIT OUT NULL LINES AT FILE END.
$$
$$ THE HEADER DATA IS CONTAINED IN FILE
$$ "HEADER.TXT" AND THE FOOTER DATA IN
$$ FILE "FOOTER.TXT"
$$
   STRING/FNAM1(40),GNAM1(40),HNAM1(40)
$$
   DATA/FNAM1,'@UGFMDISK:UGMGR:DAVID:HEADER.TXT'
   DATA/GNAM1,'@UGFMDISK:UGMGR:DAVID:PUNCHFILE.PTP'
   DATA/HNAM1,'@UGFMDISK:UGMGR:DAVID:FOOTER.TXT'
$$
   FETCH/TXT,1,FNAM1,IFERR,ERR1:
   APPEND/1
   FETCH/TXT,2,GNAM1,IFERR,ERR2:
   RESET/2
   LDEL/2,START,10,END,10
   APPEND/2
   N=GETL(2)
   LDEL/2,START,N,END,N
   FILE/TXT,2,GNAM1,IFERR,ERR4:
   FAPEND/TXT,1,GNAM1,IFERR,ERR2:
   APPEND/1
   FAPEND/TXT,1,HNAM1,IFERR,ERR3:
   FILE/TXT,1,GNAM1,IFERR,ERR4:
$$
   TERM:
   HALT
$$
   ERR1:MESSG/'ERR1:',' ERROR IN FETCH #1'
     JUMP/TERM:
   ERR2:MESSG/'ERR2:',' ERROR IN FAPEND: MAIN FILE'
     JUMP/TERM:
   ERR3:MESSG/'ERR3:',' ERROR IN FAPEND: TRAILER FILE'
     JUMP/TERM:
   ERR4:MESSG/'ERR4:',' ERROR IN FILING PRODUCT'
     JUMP/TERM:
```

The program uses the two scratch file areas in GRIP to read, sort and edit the punch files so that the sets of commands in the header and footer files may be added on. The strings FNAM1 etc contain the file names as character strings so that in order to process another punch file, only one file name has to be changed. It is stored under the original name in the corrected form.

APPENDIX C

EXTRA CNC MILL COMMANDS

Preliminary commands contained in HEADER.TXT

```
10    %
20    OOOOO<CR><LF>
30    G00G17G20G22<CR><LF>
40    G40G49G546G4<CR><LF>
50    G80G91G94G98M77<CR><LF>
60    G28 Z0. M38<CR><LF>
70    G28 X0. Y0. M48<CR><LF>
80    M00<CR><LF>
90    (OPTIONAL ACSII DESCRIPTOR)<CR><LF>
100   M06 T<CR><LF>
110   M03 S<CR><LF>
120   G90G00 G43 Z+2.0 H<CR><LF>
130   X0.0Y0.0Z3.0<CR><LF>
```

Commands contained in trailing file FOOTER.TXT

```
10    G90 G00 Z+3.0 M09<CR><LF>
20    G80 G40 G49 M05 G28 Z-2.0<CR><LF>
30    M46<CR><LF>
40    M30<CR><LF>
```

Line 90 in HEADER.TXT may be used to insert program names and tool information in man-readable form. Line 20 may also be used for path desriptions e.g. 20 O1573<CR><LF>.

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